JAMES WATT

AND THE APPLICATION OF SCIENCE TO THE MECHANICAL ARTS:

AN INAUGURAL ADDRESS DELIVERED IN THE UNIVERSITY OF GLASGOW.

NOVEMBER 11th, 1889.

BY

ARCHIBALD BARR, B.Sc.,

PROFESSOR OF CIVIL ENGINEERING AND MECHANICS IN THE UNIVERSITY OF GLASGOW; FORMERLY PROFESSOR OF CIVIL AND MECHANICAL ENGINEERING IN THE YORKSHIRE COLLEGE, LEEDS.

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It would appear to be the chief distinctive characteristic of the Nineteenth Century that it is the age of Applied Science. The ancients were perhaps our superiors in literature, in art, and in philosophy, for though in all departments of thought and action, continual progress must be made, still the most noble individual works in literature and in art, and the most far-reaching departures in philosophy, belong to long past times. The science of mathematics has been the growth of centuries, and mechanics, astronomy, and mathematical physics have grown with its growth. Those who rank to-day as the greatest musicians the world has seen are men of a past time. Physics and chemistry and geology have made marvellous progress during this century, but though these sciences may rank with astronomy as worthy, for their own sakes, of the devotion of the noblest minds, yet it is their application to the material wants of man that is to-day the most potent incentive to their study and the chief cause of their growth and diffusion. The sciences of medicine and surgery have no doubt

undergone an almost complete change in method, and an unprecedentedly rapid development since this century began, and with them the science of biology, in all its branches, has grown from small beginnings. Still the conditions of life to-day are vastly more in contrast with those of last century in the material environment of man, than in any other aspect.

Works which were produced ages ago still remain the grandest creations of the human mind and hand, in the realms of literature and of art, but few, if any, of the inventions of our forefathers remain in use. Even those connected with the most necessary processes in preparing clothing to cover, and food to nourish us, have entirely changed. The distaff and the spinning wheel alike are superseded, and the millstone, which may be regarded as the last relic of the age of stone, and which only ten years ago held its place as almost the only contrivance for the grinding of corn, may be looked upon to-day as a thing of the past, which must soon find its only place in historical collections.

Mechanical arts have necessarily been practised in all ages, and have developed and expanded through the centuries, but that which is the distinctive feature of the arts of the present is that those which have come down to us from ancient times have been entirely changed in method, and greatly extended in scope, by the aid which science has given to them; and the growth of scientific knowledge has given rise to new arts, which could not even have been dreamt of by our forefathers. In any retrospect of this modern development of the mechanical arts, and of the aid which science has given to them, we cannot fail to be led back to the genius of James Watt as

the fountain-head in which the stream of progress had its source. With Watt, engineering, as we know it, may be said to have begun. His life must therefore be full of lessons for those who inherit the rich fruits of his labour, and especially for those who are to devote their lives to the profession which he may be said to have founded.

And at the very outset, we find foreshadowed the lesson which his life has for us as engineers. The grandfather of the great engineer was a teacher of mathematics and navigation ; his tombstone describes him as "Thomas Watt, Professor of Mathematics in Crawfordsdyk." Of his two sons, John was a land-surveyor and teacher of mathematics, and James, the father of the engineer, was a carpenter and shipwright, and a general merchant. James Watt must therefore have inherited —if there is heredity in such matters—all the elements which go to make the successful engineer. Theory and practice may be said to have been blended in the very flesh and blood of the boy who was born in Greenock in 1736.

At the time when Scotland was agitated by the Stuart rebellion of 1745, we get a glimpse of the early life of Watt, whose labours were destined to work a change in the conditions of life more wide-spread and beneficent than that which any political revolution could effect. We see a boy of the most fragile constitution, enduring all the hardships and ridicule which his weakness brought upon him in the playground, and the no less severe trials of a dunce in the schoolroom. But like many others, young and old, who are accredited dunces, Watt was simply a human being in an uncongenial and unsuitable environment. When, at the age of 14, he began the

study of mathematics, his powers soon asserted themselves, and he speedily took the lead among his schoolfellows.

In reading the lives of the great engineers, nothing strikes one more forcibly than the fact, that in all or almost all cases a mechanical bent very early manifested itself, and was allowed free exercise. A home workshop has afforded an essential part of the early training of most of those who have afterwards risen to greatness in engineering. In Watt's case we have no exception to this rule. From childhood he was accustomed to work with his hands, to make his own toys, and to work out his own ideas in models which he contrived and constructed. His father provided him with a bench and a smith's fire, and his mother encouraged him in the use of his pencil. What better early training could there be for the future engineer? I fear that in these days of long school hours and cram, when much the same tools are used to shape the young mind of whatever stuff it may be made, and for whatever sphere of action it is intended, few Watts are likely to be produced. So expert did Watt become in manual work, that we are told that it became a by-word among his father's journeymen that "Jamie had gotten a fortune at his finger-ends." Nor did he neglect reading and study. All books that came in his way were eagerly read, and, as far as his opportunities allowed, he studied natural philosophy, chemistry, and other sciences before he was 15 years of age.

His father's business, which it was originally intended that he should follow, had suffered reverses, and besides the youth's tastes went beyond the work of a common carpenter; it was therefore arranged that he should become

a mathematical instrument maker, and with this end in view he went to Glasgow at the age of 18 to learn the trade. He found no one who could instruct him in the art, but he got employment with a small tradesman, who repaired drawing instruments, fiddles, and spectacles, and sold fishing tackle. In all such work Watt was at home, and especially perhaps in the fishing tackle branch of his master's business, for he was as a boy an enthusiastic angler. But there was little chance among such surroundings of his learning much that would lead to future success in life.

He had made the acquaintance of Dr. Dick, Professor of Natural Philosophy in the University, and on his advice, and bearing a letter of introduction from him, Watt started for London in the following year, his journey occupying a period that would now suffice for a voyage to New York and back. After considerable delay Watt secured a place, paying 20 guineas, and his labour, for a year's instruction. He was already so expert with his hands, and so apt in learning anything of a mechanical nature, that one year sufficed for his apprenticeship. During this time he contrived to earn some small amount by getting up early and working on his own account before he went to the shop. His work was however carried on in constant fear of the pressgangs and kidnappers, because, as he himself has said, "If I was carried before my Lord Mayor, I durst not avow that I wrought in the City, it being against their laws for any unfreeman to work, even as a journeyman, within the Liberties!"

His hard work told upon his weak constitution, and suffering from "violent rheumatism," "a gnawing pain

in his back," and "weariness all over his body," he returned to Greenock bearing with him a stock of tools, materials of which to make others, and a work on the construction and use of mathematical instruments. His whole future life was overshadowed by constant dyspepsia and sick headaches, and what may have been only the natural effect of this, he lived in chronic despondency. Long afterwards he wrote to his partner Boulton, who lay ill in Cornwall, and complained of lowness of spirits, "There is no pitch of low spirits that I have not a perfect notion of from hanging melancholy to peevish melancholy. You must conquer the devil when he is young." And not only from within but from without difficulties and often despair overshadowed him, and the smallest difficulty or reverse worried and vexed him beyond measure. He must indeed have had a good heart beneath it all, when he could make and maintain so many close friendships. Dr. Robison has written of him—"I have seen something of the world, and am obliged to say that I never saw such another instance of general and cordial attachment to a person whom all acknowledged to be their superior."

It happened that at the time Watt returned to Scotland, a valuable collection of astronomical instruments had been bequeathed to the University by a Scottish merchant long resident in Jamaica; and we find Watt writing from Glasgow to his father in Greenock, under date Oct. 25, 1756—"I would have come down to-day, but that there are some instruments that are come from Jamaica that Dr. Dick desired that I would help to unpack, which are expected to-day." The minutes of a University meeting held on the following day contain

the statement that "Several of the instruments from Jamaica having suffered by the sea-air, especially those made of iron, Mr. Watt, who is well skilled in what relates to the cleaning and preserving of them, being accidentally in town, Mr. Moor and Dr. Dick are appointed to desire him to stay some time in town to clean them, and put them in the best order for preserving them from being spoiled." And six weeks later the same records show that "a precept was signed to pay James Watt five pounds sterling for cleaning and refitting the instruments lately come from Jamaica."

Watt next attempted to begin business as an instrument maker in Glasgow, but trade customs and prejudices were in his way. The corporation of Hammermen would not permit one who was neither the son of a burgess, nor a craftsman according to the usages of the trades, to open even the smallest place of business within the city, nor even to use a workshop for the carrying on of his favourite experiments.

At this juncture his connection with the University stood him in good stead. The Senate having complete control of all that went on within the University precincts, granted Watt the use of rooms and a workshop in the College buildings, and appointed him "instrument maker to the University." Here he could ply his trade and carry on his business free from molestation by the city craftsmen. Nor did the professors grudge him any help that their science could afford. They made him their friend and confidant in their work to the mutual advantage of their science and his practice.

He at first occupied himself especially in the making of navigational instruments, and he managed to earn a

moderate living by the sale of these. Though he did not attend any classes in the University, he devoted himself very earnestly to the study of science. He thus gained the friendship of Dr. Black, who was lecturer on Chemistry, and also held in succession the Chairs of Anatomy and the Practice of Medicine. Dr. Black thus speaks of him—"I soon had occasion to employ him to make some things which I needed for my experiments, and found him to be a young man possessing most uncommon talents for mechanical knowledge and practice, with an originality, readiness, and copiousness of invention, which often surprised and delighted me in our frequent conversations together. I had also many opportunities to know that he was as remarkable for the goodness of his heart, and the candour and simplicity of his mind, as for the acuteness of his genius and understanding. I therefore contracted with him an intimate friendship, which has continued and increased ever since that time."

But Watt made another friendship in his College workshop, a friendship which had a great influence upon all his future life. A young student of Natural Philosophy—John Robison by name—was brought to the workshop by three of Watt's patrons—Dr. Simpson, Professor of Geometry; Dr. Dick, Professor of Natural Philosophy; and Dr. Moor, Professor of Greek, all men with strong leanings towards Watt's favourite pursuits. Robison, who afterwards succeeded Dr. Black as lecturer on Chemistry (in which science he got his first instruction from Watt), and who afterwards occupied the chair of Natural Philosophy in Edinburgh University, gives remarkable testimony to the mechanic's knowledge of

the exact sciences. "After first feasting my eyes with the view of fine instruments, and prying into everything, I conversed with Mr. Watt. I saw a workman, and expected no more; but was surprised to find a philosopher, as young as myself, and always ready to instruct me. I had the vanity to think myself a pretty good proficient in my favourite study, and was rather mortified at finding Mr. Watt so much my superior."

Watt tells us that he owed to his friend Robison the first suggestion of "the idea of applying the power of the steam-engine to the moving of wheel-carriages, and other purposes; but the scheme was not matured, and was soon abandoned on his going abroad."

The increase of his business and his approaching marriage led him to give up his rooms in the College, and in partnership with a man of some little means he opened a shop in the Saltmarket. Some three years later he removed to more commodious premises, as we learn from an advertisement in the *Glasgow Journal* of 1st December, 1763, to the effect: "James Watt has removed his shop from the Saltmercat to Mr. Buchanan's land in the Trongate, where he sells all sorts of Mathematical and Musical Instruments, with variety of Toys and other goods." His connection with the University was, however, still maintained after he had gone into the toy business. He remained on terms of the most intimate professional intercourse with the science professors, and enjoyed their friendship in a more social way in the club which they frequented.

His abilities and knowledge were so extraordinary, and so widely did they become known, that his contemporaries seem to have considered him well nigh omnipotent in all

matters pertaining to practical mechanics. When an organ was required for a masonic lodge in Glasgow, Watt was asked to build it, though it was well known that he had no ear for music, and could hardly tell one note from another. But in this matter we have revealed to us the secret of his success, and the chief lesson which his life must have for you who are entering upon the profession which he followed and so greatly adorned. He called science to his aid where his experience and his natural gifts failed him. He studied the principles which must guide him, from "Smith's Harmonics," and by a thorough understanding of the "theory of the beats of imperfect consonance," he produced an organ which won the approval and even the high commendation of musical men. Nor did he make organs alone, but fiddles, flutes, and other musical instruments came from his hands. Dr. Robison further tells us that "Hardly any projects, such as canals, deepening the river, surveys, or the like, were undertaken in the neighbourhood without consulting Mr. Watt; and he was even importuned to take charge of some considerable works of this kind, though they were such as he had not the smallest experience in."

After he had married and had begun to feel the necessities of a growing family pressing upon him, he forsook his original occupation of instrument-making, and took to land surveying and civil engineering.

It is worthy of passing remark that both Watt, who may be looked upon as the founder of modern mechanical engineering, and Smeaton, who holds a corresponding place in regard to civil engineering, were mathematical instrument makers to trade.

Watt made a survey for a Forth and Clyde Canal, and this involved his appearance before a Committee of the House of Commons. I fear, however, that he would not have succeeded as a promoter of great national schemes in civil engineering work, as he seemed to lack some of the qualities necessary for success in the launching of such projects. Indeed, he had enough of Parliamentary Committees on this one occasion, as appears from a letter to his wife written from London about this "confounded Committee of Parliament." He writes—"I think I shall not long to have anything to do with the House of Commons again :—I never saw so many wrong-headed people on all sides gathered together. As Mac says, I believe *the Deevil* has possession of them!"

He persevered, however, with civil engineering works on a considerable scale, and attained some celebrity in this branch of the profession, in river improvements, bridge, canal, and harbour works. Perhaps the greatest of his civil engineering works were his survey for the Crinan Canal and a survey for a canal between Fort-William and Inverness along almost the same line as that followed by the Caledonian Canal afterwards constructed by Mr. Telford.

Here I must make a brief digression to explain Watt's place among the inventors of the steam engine.

The earliest workers in the investigation of the powers and applications of steam were, naturally and necessarily, learned and scientific men, according to their times, rather than mechanics. Such were Porta, Rivault, De Caus, the Marquis of Worcester, Huyghens, and Savery, who laboured in the 17th century. With the beginning of the 18th century the steam engine may be said to

have passed from the hands of the philosophers to those of the mechanics. The essential details for an engine of a kind had been invented, and the scientific principles and data had been sufficiently discovered. The mechanical arts had so far progressed that the parts of the engine could be constructed, though indeed in a very rude manner. All that was wanted was a mechanic of ability and resource to take the matter in hand. Such discovered himself in Thomas Newcomen, the blacksmith of Dartmouth.

The miners of Cornwall had begun to encounter difficulties in their search for richer minerals at deeper depths than they had hitherto attempted to reach, owing to the frequent flooding of the mines. Necessity produced her proverbial offspring. Newcomen constructed engines which were much in demand for mine pumping. In these engines steam at atmospheric pressure was admitted under a piston, which, by the descent of heavy pump rods, was caused to rise to the top of the cylinder. The communication with the boiler having been closed, and the cylinder cooled by the application of water on the outside, the vacuum produced caused the piston to descend, raising the pump rods and water.

To prevent the access of air to the cylinder while the vacuum existed under the piston, Newcomen maintained a layer of water on the top of the piston. One day, while watching one of his engines at work, he was surprised to see it animated with unwonted vigour, and, searching for the cause, he found a hole in the piston which allowed the water to leak into the cylinder, accelerating the condensation, and producing a much

better vacuum than he had previously attained. This at once suggested to Newcomen the expedient of injecting condensing water into the cylinder, instead of applying it to the outside. This and other improvements, including the self-acting gear which the valve-boy Potter contrived, to afford himself leisure from his duty of turning the cocks at each stroke of the engine, enabled Newcomen to produce much improved engines, whose only fault in the eyes of his clients was that they were too greedy in fuel.

A model of Newcomen's engine belonging to the University, and still preserved as one of the treasures of this place, was entrusted to Watt for repair in 1763. This circumstance could hardly fail to produce great results. Watt had all the necessary knowledge of science, he could work with his own hands, and further he possessed the instincts of a student and those of a scientific discoverer. Dr. Robison again says of him, "Everything became to him a subject of new and serious study,—everything became science in his hands." Watt studied the model, experimented with it, discovered its wastefulness of steam, and set to work systematically to find the cause. He made numerous experiments, in the course of which he discovered the latent heat of steam, the theory of which had shortly before been worked out by his friend Dr. Black, unknown to Watt. He arrived at and clearly enunciated the principle which must underlie any attempt to greatly reduce the waste of fuel in the Newcomen engine. He saw that the chief source of loss lay in the cylinder being cooled at each stroke only to be reheated at the expense of the new charge of steam. He laid it down as an axiom, as he

himself tells us, "that to make a perfect steam-engine, it was necessary that the cylinder should be always as hot as the steam which entered it, and that the steam should be cooled down below 100° in order to exert its full powers."

This led at once to his first great invention—from which all the others flowed—that of the separate condenser. The invention was fully worked out in his mind while he was taking an afternoon walk on Glasgow Green, and in a few days he had it put to the test of experiment.

Here then we have characteristic examples of two processes of invention. Newcomen, the blacksmith, made his success through accidental observation; Watt, the man of science, made his great invention by reasoning founded upon the knowledge of the laws of nature, which he had acquired through a long course of study and experiment. There was no accident here, his method was bound to lead him to the desired result.

Watt's other inventions are too numerous to mention, and most of them—such as the parallel motion, the governor, and the steam-engine indicator—are well known to have come from him. But the very multitude of his inventions makes his name be little associated with some of his most fruitful works. Had he made no other invention, or had he been of a more self-assertive disposition, his name would probably have become known wherever business is conducted, in connection with his invention of the method, still almost universally in use, of copying letters by means of the copying press.

It would seem to be the common fate of all great and

novel inventions to raise a storm of opposition from those whom they are most calculated to benefit. Dud Dudley's invention of the process of smelting iron by means of coal instead of charcoal brought him only persecution from the ironmasters, and the destruction of his works by rioters at their instigation. The steel makers of Sheffield attempted to get the Government to prohibit Huntsman from working his great invention —the cast steel process—and nearly succeeded in driving the cutlery trade out of their own hands, and out of Sheffield. David Mushet's discovery that the "wild coals" were ironstones of great value, excited for years a strong prejudice against him in the minds of the ironmasters of Scotland, who have since made not only their own fortunes, but in great measure the Scotland of to-day, through the working of those blackband ores. Neilson's invaluable invention of the hot blast for smelting furnaces was not only ridiculed by the ironmasters, but so stoutly resisted that for years he was unable to get it even tried on a practical scale. So again the landed proprietors, who had perhaps most to gain from the opening up of communications through the country, strongly opposed the early railway projects. They supposed that they were to be reduced to beggary by the "infernal railroads," as one landowner called them, declaring that he "would rather meet a highwayman, or see a burglar on his premises, than an engineer!" Many more such instances might be quoted.

We need not, therefore, be surprised to find that Watt's copying process, though brought out practically in its present state of perfection, found little favour at first with many business men; but it is curious now,

after the invention has for more than one hundred years been almost indispensable to the class of men who then resented its introduction, to read of the bitterness of the opposition which it met with. The fear that "it would lead to the increase of forgery" ran so high, that on one occasion when Smeaton and Boulton (Watt's partner) were sitting in a London coffee-house, they heard a gentleman exclaiming against the copying machine, and "wishing the inventor was hanged and the machines all burnt." No one could attempt to estimate the value to the world of this single invention, and still comparatively few people now know to whose labours and knowledge they owe the boon.

As an example of his more purely scientific work, I need only refer in passing to the part he took in the discovery of the composition of water, which gave rise to a long and somewhat bitter controversy.

I have referred to the patronage and protection which the University extended to Watt at the most critical period of his life, and the aid which he received from the science which he learned within its walls. The Senate of those days earned for their ancient University the immortal credit of having started James Watt upon that series of inventions which have so altered all the conditions of life and labour.

The happy results which have flowed from this early patronage of the mechanical arts, and the application to them of the science of our predecessors here, need not be dwelt upon, and cannot be enumerated. Everywhere they are apparent, and every day they are being added to and extended. Old arts are giving place to new, and "the Scottish brass-smith's idea," to quote the words of

Carlyle, "is rapidly enough overturning the whole old system of society." To the labours of Watt, and therefore, in a considerable measure, to our predecessors on the Senate of this University, we owe the first necessary steps in the modern scientific development of the arts both of peace and of war.

In later times again, the Senate of this University, by its liberal encouragement of applied science in the labours of another great master of the art of invention —labours carried out, I believe, in the very rooms in which Watt worked and studied—has been largely instrumental in bringing about another of the greatest and most beneficent changes in the conditions of the lives of men. If through the labours of Watt the Atlantic Ocean may be said to have been narrowed from a month of discomfort and danger to a week of ease, so largely through the labours of Sir William Thomson, the separating sea may almost be said to have ceased to exist as a barrier between the thoughts and lives of men of our race. These are among the greatest and most beneficent of the applications of science to the wants of man, for all must agree with Macaulay that "Those projects which abridge distance have done most for the civilization and happiness of our species."

The encouragement and assistance rendered by the University in those two cases of conspicuous success and benefit to mankind have been amply recognized by those to whom they were extended, in the foundation of the Watt Prize and the Thomson Experimental Scholarships.

In a letter to Principal Taylor, dated June 3, 1808,

James Watt thus expresses his feelings towards the University in founding the prize since known by his name :—"Entertaining a due sense of the many favours conferred upon me by the University of Glasgow, I wish to leave them some memorial of my gratitude, and, at the same time, to excite a spirit of inquiry and exertion among the students of Natural Philosophy and Chemistry attending the College; which appears to me the more useful, as the very existence of Britain, as a nation, seems to me, in great measure, to depend upon her exertions in science and the arts." After specifying how his donation is to be invested, and the subjects in applied science for essays upon which the prize he founds is to be offered, he proceeds :—"and I request that no public mention be made of this donation, by paragraphs in the newspapers, or otherwise, until a prize come to be adjudged; not being, as far as I know, actuated by vanity, but by a desire to stimulate others to do as I have done."

And the University Records contain an equally interesting letter from Sir William Thomson to Principal Barclay, dated Sept. 6, 1869, from which I extract these words :—"I have always felt grateful to yourself and my colleagues for the liberal and friendly spirit which has been shown me in respect to my connection with telegraphic enterprise. I also feel that whatever success may now come I owe in a great measure to the facilities for experimenting which the College has afforded me. I am anxious to mark my sense of these benefits, by setting aside something of what I have received to assist in promoting the cultivation of experimental investigation in Glasgow University, and I therefore beg you to offer

£1,000 from me for the acceptance of the Senate for that purpose."

If, then, it should still be necessary anywhere to plead the cause of education in matters relating to the application of science to the arts surely it is not from this platform.

In past ages, when the Universe was supposed to be divided against itself, when one system of laws was believed to govern the higher manifestations of the creative power, and quite another and baser set of principles to underlie all that concerned man's immediate material surroundings, we cannot wonder that the pursuit of the arts of construction and production were deemed beneath the notice of the noblest and most gifted men. Then the mechanical arts stood apart, and deserved and required no place in the Universities, because they had little or no connection with other departments of thought and action. For it is the function of a University to teach not what is limited and isolated in human knowledge, but to teach each separate department of knowledge in its relations to all others.* Now, however, when we see in all nature the manifestations of one and the same code of never-changing, never-varying laws, surely we may look upon the work of the engineer in "directing the great sources of power in nature for the use and convenience of man" as a vocation as noble, and as worthy of the highest order of mind, as that of the scientific discoverer, who deciphers, from their manifestations in nature, the principles which the engineer applies. And, surely, when a new application of the laws of nature is invented, which will open fresh possibilities

* See "The Unity of the Sciences," by Principal Caird.

in the lives and actions of man, he by whose genius and knowledge it is created, may with as much joy and pride cry out, "Eureka, Eureka," as may he who first discovers a new and far-reaching principle of the universe, and sheds fresh light upon a dark page of the book of nature.

In the present state of man's progress, when the aid which science can give to the arts has not been fully accepted and made use of, devotion to the creative arts may not demand for success the exercise of a mind so richly endowed and cultured as is necessary for the inquiry into the secrets of nature; still in itself it may even appear to be a higher form of exercise of the powers with which man has been endowed. Bacon indeed asserts—"The introduction of new Inventions seemeth to be the very chief of all human Actions. . . . Inventions make all Men happy, without either Injury or Damage to any one single Person. Furthermore, new Inventions are, as it were, new Erections and Imitations of God's own Works."

And if it is unnecessary, as I have said, at least in this University, to plead the cause of education in the sciences applicable to the work of the engineer, it is equally unnecessary to dwell upon its value in addressing present or future members of the engineering profession. If proof is wanted of the value set by engineers themselves upon such a course of study as that which enabled Watt to strike out into new and untrodden paths in invention and discovery, surely it is to be found in the liberal support now being given in all parts of the country towards the founding and equipment of schools of engineering science.

Almost every university, university college, and technical school, now offers instruction in the science of engineering, and the support extended to these schools has not stopped with the founding of chairs and lectureships. Laboratories have been erected and equipped in which experimental investigations may be made on matters relating to engineering principles and practice.

There is, I fear, a rather common impression that an engineering laboratory is merely a workshop in which students are instructed, or supposed to be instructed, in handicraft work. It is not so in most cases, and it ought not to be so. There are perhaps three principal subjects in engineering science which lend themselves especially to, and indeed demand, experimental treatment, and those are the three subjects in relation to which my three predecessors in this chair are so widely known and highly honoured in the engineering world. Professor Gordon is principally known in connection with his work on the strength of structures, Professor Rankine's fame largely rests upon his invaluable contributions to the science of thermodynamics and its application to the theory of the steam engine, and my immediate predecessor, Dr. James Thomson, will ever have an honoured name where the science of hydraulics is studied or applied. An engineering laboratory should be fitted up with the appliances necessary for the carrying out of experimental investigations in at least those three subjects or groups of subjects.

Testing Machines should be provided by aid of which experiments may be made on the strength and elasticity of the materials used in civil and mechanical engineering construction, and on the strength and stiffness of

elementary structural parts, such as columns, struts, and beams.

A specially designed steam boiler and engine should be provided, so that students may be instructed in the experimental methods of investigating the economy of steam engines and boilers. No doubt the results obtained from such an engine as can be provided and used in a College laboratory cannot be an absolute guide as to the results that will be obtained from engines under all the conditions of ordinary practice, still the methods of accurate engine testing in the use of indicators, friction brake dynamometers, and other appliances, and in the quantitative determination of the various losses of energy, can be taught and practised, and it must be remembered that such education in methods and principles, and not the imparting of separate facts and data to be remembered, is the main object of a University course.

The laboratory equipment should further include a set of tanks and other hydraulic apparatus to enable the students to carry out for themselves such experiments in the gauging of water, the efficiency of hydraulic motors and kindred subjects, as those which Dr. Thomson has carried out with so much ability, and such lasting benefit to engineering practice. Many minor subjects may also be experimentally treated in the laboratory with great advantage, such as the friction of lubricated and non-lubricated surfaces, and the efficiency of different methods of transmitting power.

Such matters cannot be learned in the ordinary course of pupilage or apprenticeship. The functions of engineering laboratories are thus referred to by Professor Kennedy, F.R.S., who must, in large measure, be

regarded as the founder of the system now almost everywhere adopted:—"In an ordinary pupilage a young engineer does not have much opportunity of studying such things as the physical properties of the iron and steel which he has to deal with, nor the strength of those materials, nor the efficiency of the machines he uses, nor the relative economy of the different types of engines, nor the evaporative power of boilers. These things, however, are only types of many others about which it is essential, not only that he should know something, but that he should form some definite working opinion. . . . They are, to a wonderful extent, suited to set the student free from the thraldom of the engineering pocket-book (making 'every man his own Molesworth' as it has been put), by helping him to determine for himself, or at least to see practically how other people have determined, all the principal engineering constants, from the tenacity of wrought iron to the calorific value of coal, or the discharge co-efficient of an orifice. Further, a healthy scepticism of uncritical generalisations, or of uninvestigated facts, is fostered by nothing so surely as by a personal and practical knowledge of what accurate experiments really are." *

And not only do such laboratories supply a connecting link in the engineer's training, between his work in the lecture room and his dealings with actual matter and energy in the practice of his profession or trade; but they enable the College work to be maintained in close connection with the engineering practice of the district, by supplying a want often felt, and largely taken advantage

* See Kennedy on "Engineering Laboratories," *Minutes of Proceedings of The Institution of Civil Engineers, Vol. lxxxviii.*